N 70 41916

NASA TECHNICAL MEMORANDUM

NASA TM X-52873

NASA TM X-52873

SINUSOIDAL PRESSURE GENERATOR FOR TESTING PRESSURE PROBES

by Ted W. Nyland
Lewis Research Center
Cleveland, Ohio

TECHNICAL PAPER proposed for presentation at
Twenty-fifth Annual Conference of the Instrument Society of America
Philadelphia, Pennsylvania, October 26-29, 1970

SINUSOIDAL PRESSURE GENERATOR FOR TESTING PRESSURE PROBES

Ted W. Nyland
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

E-5426

ABSTRACT

The design and operating characteristics of a sinusoidal pressure generator are described. The generator is capable of producing sinusoidal pressures at frequencies between 300 and 5000 Hz with peak-to-peak pressure amplitudes to 5 psi. Two similar generators have been constructed, one of which oscillates around atmospheric pressure, and the second of which oscillates around adjustable static pressure levels to 120 psig. The generator design is based on the use of a resonant air column which is set into oscillation by the impingement of an annular air jet on circular shaped sharp edge. The frequency of oscillation is varied by adjustment of a tuning piston which varies the air column length. The generator is constructed from a 1 inch O.D. tube 13 inches long. Instrumentation for making frequency, amplitude, and phase angle measurements is described. Data describing operating conditions and wave shape distortion is given. The generator is useful in determining the frequency response of small pressure transducers, pressure probes, and characteristics of small diameter infinite lines.

INTRODUCTION

Experiments to measure the dynamic stall characteristics of turbojet engines require many transient pressure measurements. These pressures are measured with probes consisting of short tubes (an inch or less in length) connected to miniature pressure transducers mounted within the probe support. In order to correlate pressure disturbances measured by probes at different locations and to identify frequencies of importance to the stall characteristics, the experimenter must know the amplitude and phase angle response of the probes with respect to frequency. The upper frequency of interest in this work is about 5000 hertz and dynamic pressure amplitudes up to 30 percent of the average pressure are anticipated.

To measure the frequency response of pressure probes and to study ways of extending the useful frequency response of such probes, two similar type sine wave pressure generators were developed at the Lewis Research Center. One of the generators operates at a static pressure level of one atmosphere and is described in reference 1. The second is capable of operating at adjustable static pressure levels up to 8 atmospheres. This report summarizes the design and operating characteristics of these generators. The units are capable of producing sinusoidal pressures of up to 5.6 psi peak-to-peak, over a frequency range from 300 to 5000 Hz. Measurements of amplitude ratio and phase angle are obtained by comparing data from test probes with that from a reference pressure transducer mounted flush with the inside wall of the generators.

Many different types of generators have been reported in the literature [2,3]. Transient pressure steps have been generated with shock tubes, quick opening valves and burst diaphragm devices. Determination of the amplitude and phase response against frequency using this type of generator requires a harmonic analysis of transient waveform. Various techniques for performing such analyses have been reported [2], but considerable complexity is involved both in performing the analysis and in reducing the recorded transient signal to a form suitable for analysis. Periodic pressure signals have been generated using rotating valves and flow modulators, siren tuned cavities, and piston driven devices. Some of these can produce sinusoidal waveforms if the sine wave pressure amplitude can be restricted to roughly 10 percent of the average pressure level. Other generators have been designed to meet the requirements for calibrating pressure transducers for rocket engine combustion studies where both the required pressure level and frequency range are considerably higher than the type described herein. In many of these generators, wave-shape distortion occurs at high amplitudes due to nonlinearities in the fluid properties under dynamic conditions. A sinusoidal waveform is an obvious advantage, since it eliminates the need for harmonic analysis of the measured signals. The choice of which approach is best then depends on such factors as the constancy of amplitude against frequency and the simplicity of construction and operation.

A fixed-frequency sine wave pressure generator based on a Galton whistle was used at Lewis[4] in an unpublished study of the infinite line pressure measuring technique. The successful use of this device and its inherent simplicity prompted the development of the variable-frequency generator reported herein. The following sections describe the design and operating characteristics of the generator, the instrumentation used to measure the frequency response of probes, and typical test results.

BASIC RESONATOR CONCEPT

The sinusoidal pressure generator is fundamentally a quarter wavelength closed organ pipe resonator. A diagram of the generator is shown in figure 1. Air flows through the nozzle annulus and impinges on the sharp edge of the resonator. The resulting turbulence causes the air column inside the resonator to oscillate setting up a standing wave pattern in the resonator tube. The pressure generated at any point and time along the length of the resonator is approximately given by the following equation.

$$p = P \sin\left(\frac{\pi}{2}\frac{n}{L}x\right) \sin(2\pi f t)$$

where

$$f = \frac{nc}{4L}$$

and

p	pressure at any point along resonator
P	peak pressure amplitude
L	resonator length
x	distance from sharp edge
f	frequency of oscillation
t	time
c	speed of sound
n	takes an odd value (1, 3, 5, ... etc.)

As the resonator can oscillate in any number of modes, a variable n is included in the equation. The particular mode of oscillation is dependent on the volume flow of gas (pressure drop) across the nozzle and the nozzle-to-resonator spacing. Tests have shown that for pressure drops between 0 and 5 psi, and for spacings between 0.25 and 0.01 inches, seven different oscillation modes could be achieved and stably maintained. The value which P takes on is primarily a function of the pressure drop across the nozzle but will also vary with nozzle-to-resonator spacing.

When using the resonator as a sine wave pressure generator, test ports are drilled into the resonator tube and should be located near an antinode, i.e.,

$$\sin\frac{\pi}{2}\frac{n}{L}x = \pm 1$$

For a variable frequency generator, the length L is changed by use of a tuning piston. Thus, the antinode positions will shift along the resonator length depending on the oscillation frequency and mode. From practical considerations, the test port positions must be fixed along the tube length. For the generators described herein, the axial positions were chosen such that a set of test ports would be available where the peak pressure amplitude is within 75 percent of the antinode or maximum value.

In operation, tests have shown that the pressure amplitude and wave shape can be varied by adjusting the nozzle supply pressure and/or the nozzle-to-resonator-tube spacing. For a constant spacing, increasing supply pressure will cause the sinusoidal pressure amplitude to increase to point at which wave-shape distortion becomes apparent. This distortion is primarily associated with the next higher or lower resonant frequency of the generators. As the supply pressure is further increased, more distortion is introduced until the frequency of oscillation suddenly shifts to that of the next higher mode. Oscillation in this new mode is stable, and a pressure level can be found which results in a minimum of wave-shape distortion. On increasing the supply pressure still further, the pressure amplitude increases, distortion is introduced, and a shift to the next higher oscillatory mode occurs. Similar effects occur if the nozzle-to-resonator-tube spacing is decreased while supply pressure is held constant.

Description and Operating Characteristics of Pressure Generators

A drawing of the basic pressure generator is shown in figure 2. The resonator is made from 1-inch outside-diameter tube of 0.065-inch wall thickness and is 12 inches long. The open end of the tube is tapered at 30° with respect to the tube axis to form a sharp edge. The resonant frequency is adjusted by moving the tuning piston. The tuning piston is 0.865 inch in diameter. Test ports are located along the length of the resonator tube. Three ports are used at each axial station: one for the probe under test, one for a reference transducer, and a spare. As shown in figure 2, unused ports are blocked with plugs that are flush with inner wall of the resonator tube. Also shown in figure 2, is a reference transducer and a simulated test probe. The nozzle is made from tubing the same diameter as the resonator and is 2.25 inches long. A center body is fitted inside this tube and machined to make the annular passage way for air flow. The annulus is 0.03 inch thick. The end of the plug and nozzle tube are machined flat and perpendicular to the nozzle axis. Nozzle-to-resonator-tube spacing is adjustable between 0.01 and 0.5 inch.

Two pressure generators have been constructed and operated based on the design shown in figure 2. One of the generators, the low pressure generator, operates at a static pressure level of 1 atmosphere. The second generator, the high pressure generator, operates at adjustable static pressure levels up to 8 atmospheres. A photograph of the low pressure generator is shown in figure 3. Because of the high sound levels developed by the generator, it is operated within a sound proof enclosure. The tuning piston position is remotely controlled by an electric motor and cable mechanism. The nozzle-to-resonator spacing is varied by use of a motor

driven laboratory jack. The air supply is controlled by a two stage regulator which is capable of producing a 0 to 5 psi pressure drop across the nozzle annulus. In operation, no mechanical vibration can be felt when touching the resonator tube.

Two photographs showing the high pressure generator are shown in figures 4 and 5. The nozzle and sharp edge portion of the generator are enclosed in a 6 inch diameter by 6 inch long tank. Because of this tank, the external sound levels are not high and the generator can be operated in a normal laboratory environment. The tuning piston position is controlled by an electric motor driven actuator. A pneumatic valve operator is used to control the nozzle-to-resonator-tube spacing. The nozzle supply pressure is controlled by a differential pressure regulator while a second pressure regulator is used to control the static pressure level in the tank. All seals in the systems are made with "O-rings." As was true for the low pressure generator, no mechanical vibration of the generator can be felt by touch when the generator is in use.

Operating Characteristics

Tests have been run to determine some of the more pertinent operating characteristics of the generators. For all measurements, the nozzle supply pressure and spacing were adjusted for minimum wave-shape distortion as indicated by an oscilloscope trace. In figure 6, the pressure amplitude (peak to peak) achieved in the low pressure generator is shown plotted as a function of nozzle supply pressure. Also shown plotted is the static-pressure level measured at the face of the tuning piston as a function of nozzle supply pressure. In figure 7 is shown the measured peak-to-peak pressure amplitude as a function of nozzle supply pressure measured on the high pressure generator for different static pressure levels. (The differential pressure achieved across the nozzle of the high pressure generator was limited by the supply pressure and line losses. If the data in figure 7 were normalized and plotted as the ratio of peak to peak divided by static pressure level on the ordinate, the data points would fall essentially on a single curve.) From figure 7 it is seen that as the static pressure level increases, lower differential pressures across the nozzle are required to produce given peak-to-peak pressure amplitudes in the resonator. These measurements were made using a test port next to the piston while the resonator was operating in the first mode ($n = 1$). Figures 6 and 7 show a wider operating band than is normally used. Normal useful operating pressure amplitudes for both generators are less than 1 psi peak to peak when minimum wave shape distortion is important.

Frequency spectrum analyses have been made of the generated pressure-wave shape. When operating in the first mode ($n = 1$), the third harmonic distortion (frequency associated with the $n = 3$ mode) was present in amounts ranging from 1 percent of the fundamental at 0.7 psi peak to peak to 4 percent at 5.6 psi peak-to-peak amplitude. When operating in the third mode ($n = 3$), distortion was approximately 3 percent of the fundamental and was associated with the frequency of the first mode ($n = 1$). Two typical oscilloscope tracings of the generator output measured at different frequencies with a flush mounted miniature quartz pressure transducer is shown in figure 8. Also shown for comparison is a sine wave obtained from an electronic signal generator tuned to the same frequency.

INSTRUMENTATION

Instrumentation has been set up in conjunction with the pressure generators to measure pressure amplitude, frequency, and the phase angle between the probe under test and a flush mounted reference transducer. Both generators use the same test instrumentation. A block diagram of this instrumentation is shown in figure 9. Initially, the test probe and reference transducer's signal conditioners are adjusted so that equal voltage outputs are obtained for equal pressure inputs to the transducers. For amplitude measurements, the conditioned signals are converted from alternating to direct current and measured with a digital voltmeter. Frequencies are measured using an events per unit time counter (EPUT meter).

The phase angle measurement is made by measuring the relative time delay between a positive zero crossing of the test probe signal and that of the reference transducer. First, the signals from the test probe and reference transducer are amplified and clipped to produce square waves. This is accomplished using standard operational amplifier techniques. The squared outputs of the reference and probe transducer are viewed on a dual beam oscilloscope. The scope is triggered on the zero crossing of the reference transducer. The sweep rate of the scope is adjusted for each test frequency so that either a half or a full wave of the reference signal fills 0.9 of the scope screen. In this manner, the horizontal axis is calibrated in degrees, either 200 or 400 depending on whether a half or a full wave length occupies 0.9 of the scope screen. The point of zero crossing of the test probe along the horizontal axis then gives the phase of the probe with respect to the reference transducer.

This phase angle measuring technique allows the operator to visually average a reading and remove the effects of jitter and noise included in the signals. It was found that this jitter was sufficient to preclude the use of an automatic phase measuring system which made use of a digital counter.

Estimated error for the measurements just described are ± 1 percent of the reading for amplitude measurements, ± 1 hertz for the frequency measurement, and $\pm 5^{\circ}$ for a phase measurement.

TYPICAL PROBE RESPONSE DATA

The pressure generators have been used to determine the response of a number of probe configurations. One such simulated probe is shown mounted in the generator in figure 2. It consists of a 1-inch long tube with a 0.128-inch inside diameter and a volume ratio of 0.027. This is the ratio of the volume of the cavity located in front of the transducer to the tube volume. A plot of the response of this probe is shown in figure 10. These measurements were made at peak-to-peak pressure amplitudes of 0.7 psi thereby reducing the effects of wave-shape distortion on the transducer response. Plotted are two sets of test data of amplitude ratio (in dB) and phase angle as a function of frequency. One set of data was taken using the low pressure generator and the second using the high pressure generator. Both sets of data were taken at a static pressure level of 1 atmosphere. Also plotted in figure 10 is a theoretical curve calculated for this probe from an equation derived by Iberall[5]. An end correction of $8D/3\pi$ was applied to the tube length for this calculation where D is the tube diameter. Figure 11 shows the response of the same probe measured at three different static pressure levels using the high pressure generator. It is seen that as the static pressure is increased, the effective damping appears to be less as indicated by the measured peak values.

It has been found that, when testing lightly damped probe configurations such as illustrated in figure 2, data cannot be taken within about ±3 percent of the resonant frequency. In cases such as this, the frequency of the generator will flip from a stable mode below the resonant frequency to a stable mode of oscillation above the resonant frequency. This appears to be a result of impedance effects between the test probe and resonator tube.

CONCLUDING REMARKS

Two pressure generators capable of producing sinusoidal pressures at amplitudes to 5.6 psi peak to peak, and frequencies between 300 and 5000 hertz and at static pressure levels to 8 atmospheres have been described. Normal operating pressure amplitudes for minimum wave shape distortion are less than 1 psi peak to peak. The generators consist of a resonant tube driven by an annular jet. Oscillating modes other than that of the quarter wavelength can be stably maintained. A movable piston is used for frequency adjustment. The generators are designed to measure the frequency response of pressure probes, but may also find use in testing of fluidic and other devices. Typical test data indicate that good repeatability of the generators and instrumentation has been obtained.

REFERENCES

(1) Nyland, Ted W.; Englund, David R.; and Gebben, Vernon D.: System for Testing Pressure Probes Using a Simple Sinusoidal Pressure Generator. NASA TM X-1981, April 1970.

(2) Schweppe, J. L.; et al.: Methods for the Dynamic Calibration of Pressure Transducers. Monograph 67, National Bureau of Standards, Dec. 12, 1963.

(3) Doebelin, Ernest O.: Measurement Systems: Application and Design. McGraw-Hill Book Co., Inc., 1966.

(4) Washburn, Edward W., ed.: International Critical Tables of Numerical Data Physics, Chemistry and Technology. Vol. 5. McGraw-Hill Book Co., Inc., 1929.

(5) Iberall, Arthur S.: Attenuation of Oscillatory Pressures in Instrument Lines. National Bureau of Standards J. Res., vol. 45, no. 1, July 1950, pp. 85-108.

E-5426

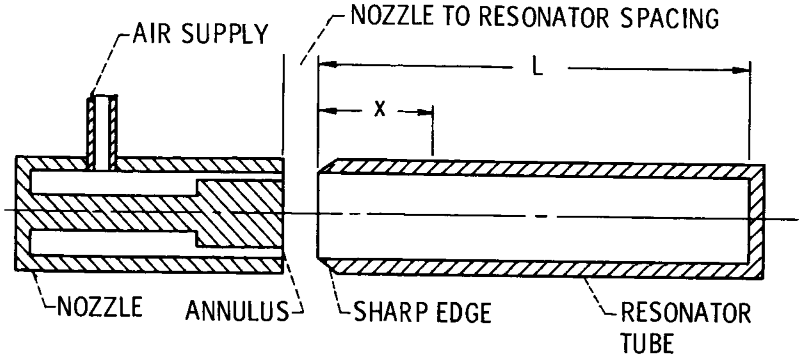


Figure 1. - Diagram of basic resonator components.

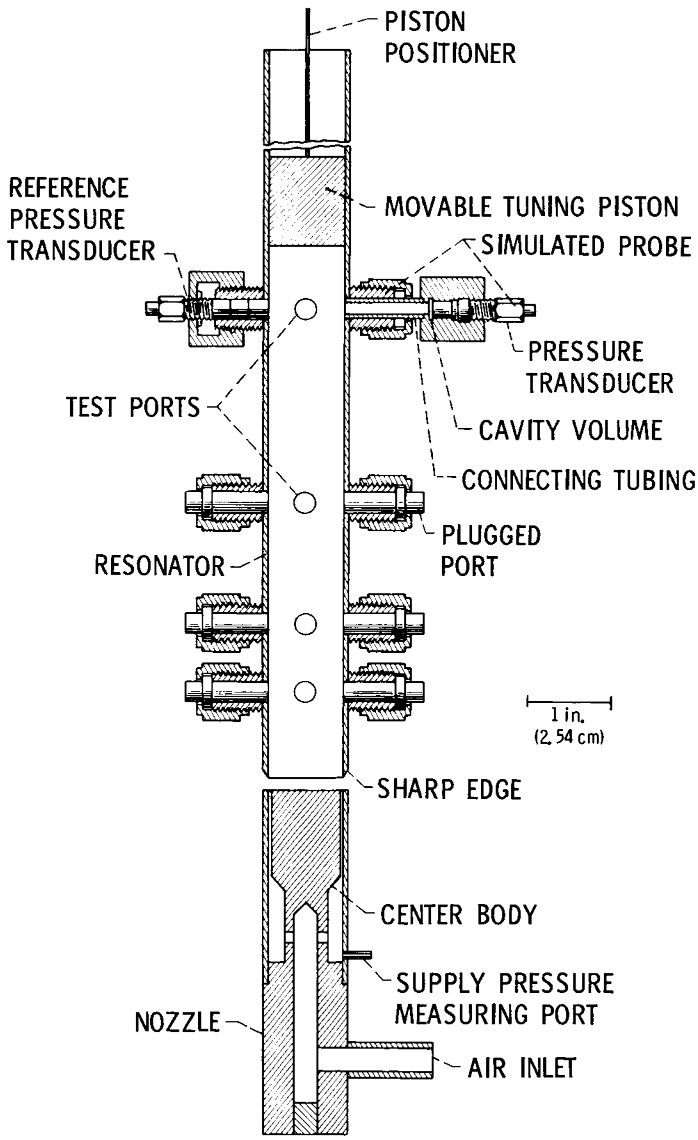


Figure 2. - Basic generator design.

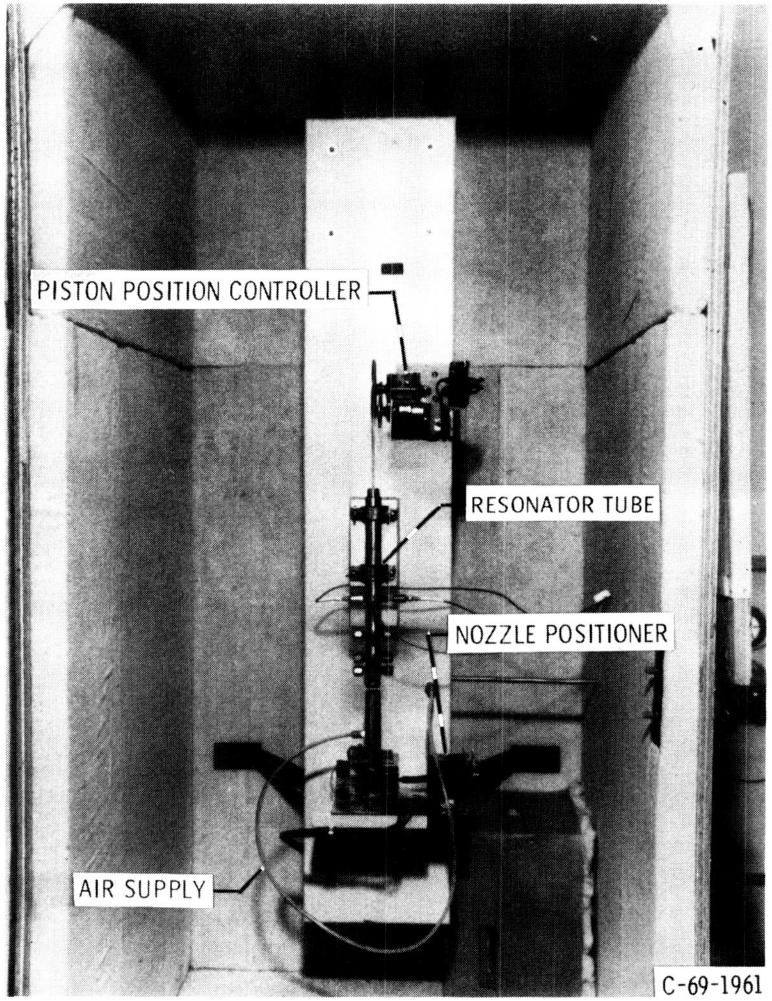


Figure 3. - Low level pressure generator.

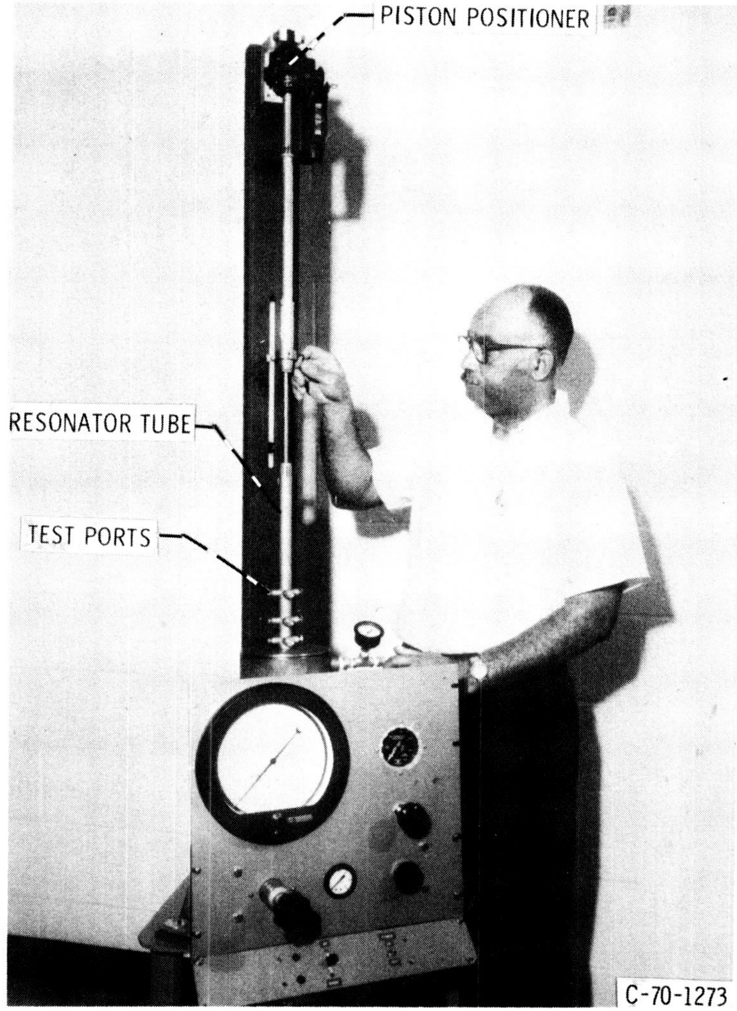


Figure 4. - Overall view of high pressure generator.

E-5426

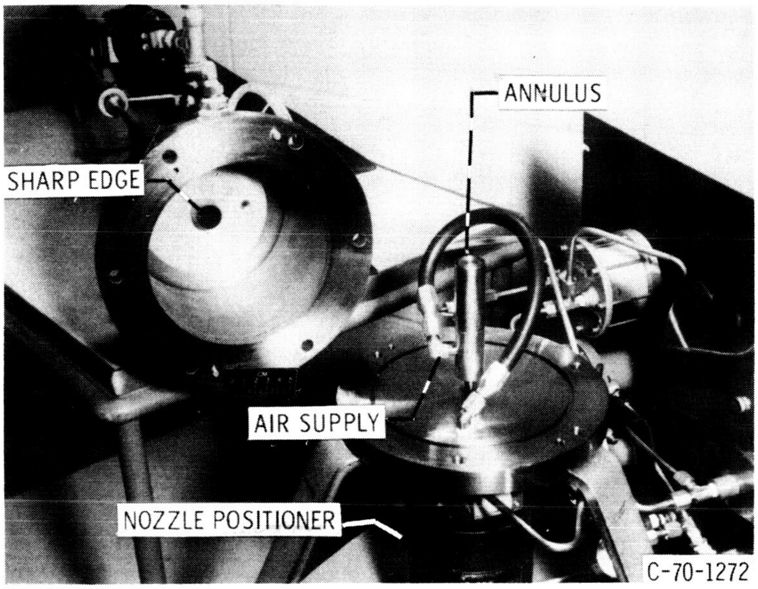


Figure 5. - High pressure generator.

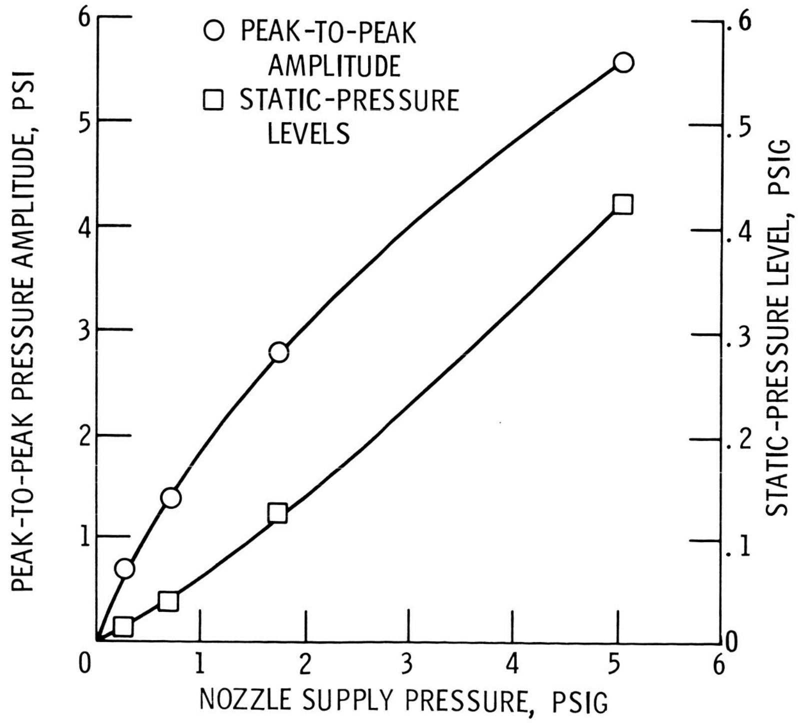


Figure 6. - Peak-to-peak sinusoidal pressure amplitude and static-pressure level as a function of nozzle supply pressure over frequency range from 350 to 4500 hertz measured on the low pressure generator.

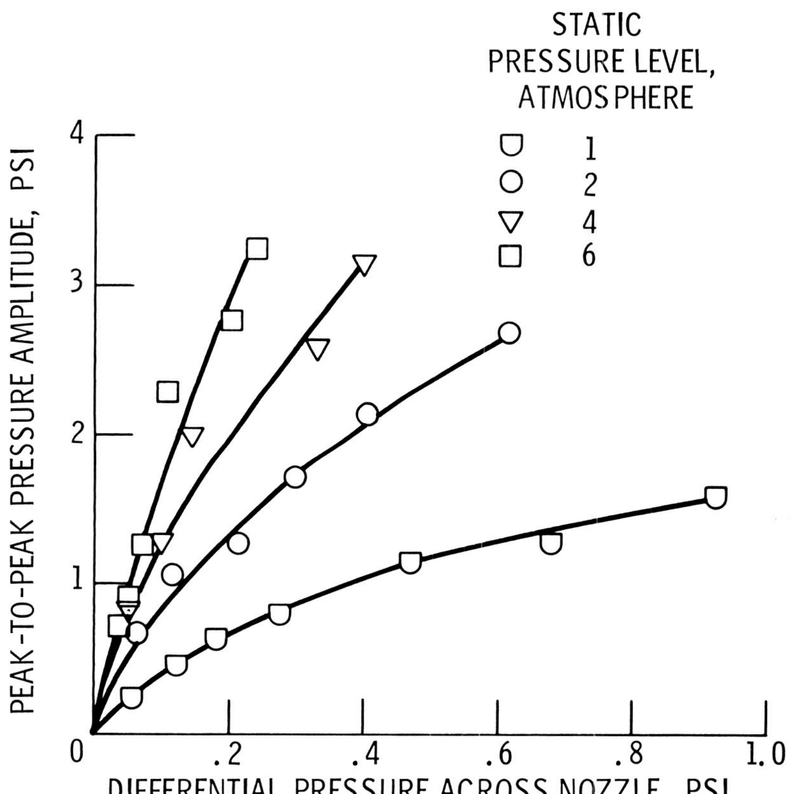
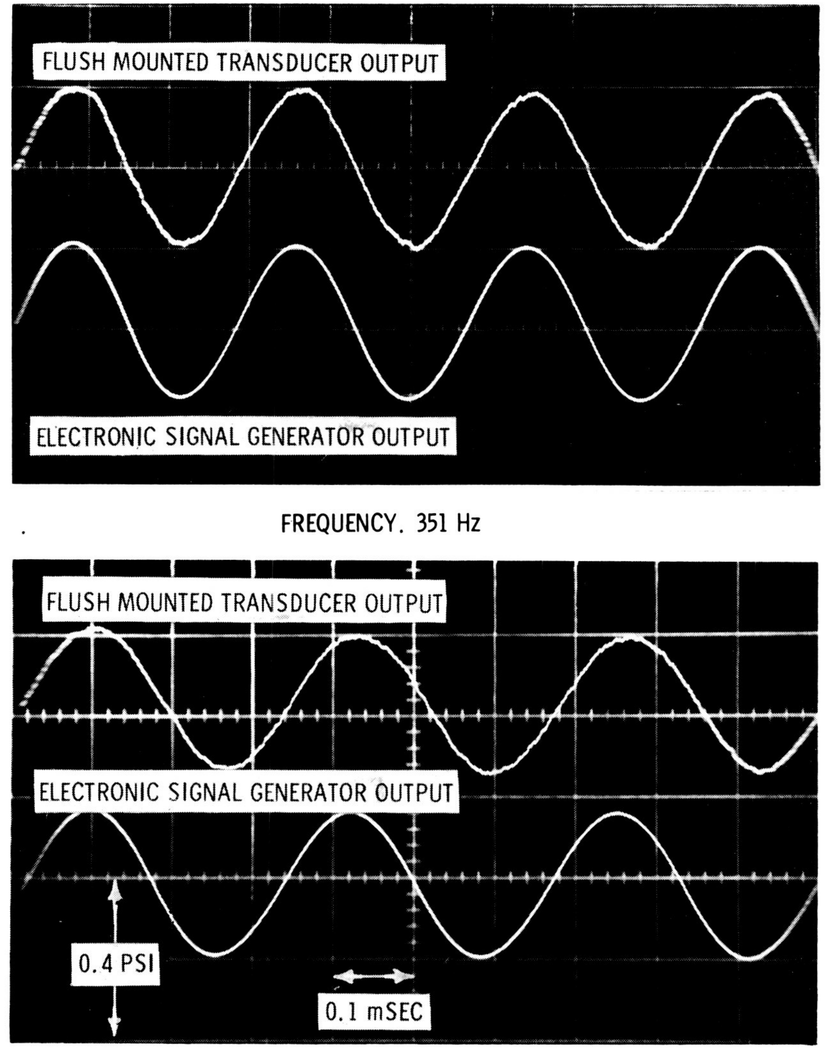


Figure 7. - Peak-to-peak sinusoidal pressure amplitude as a function of nozzle pressure differential measured on the high pressure generator at 575 hertz.



FREQUENCY, 3010 Hz

Figure 8. - Typical oscilloscope tracings of pressure wave shapes.

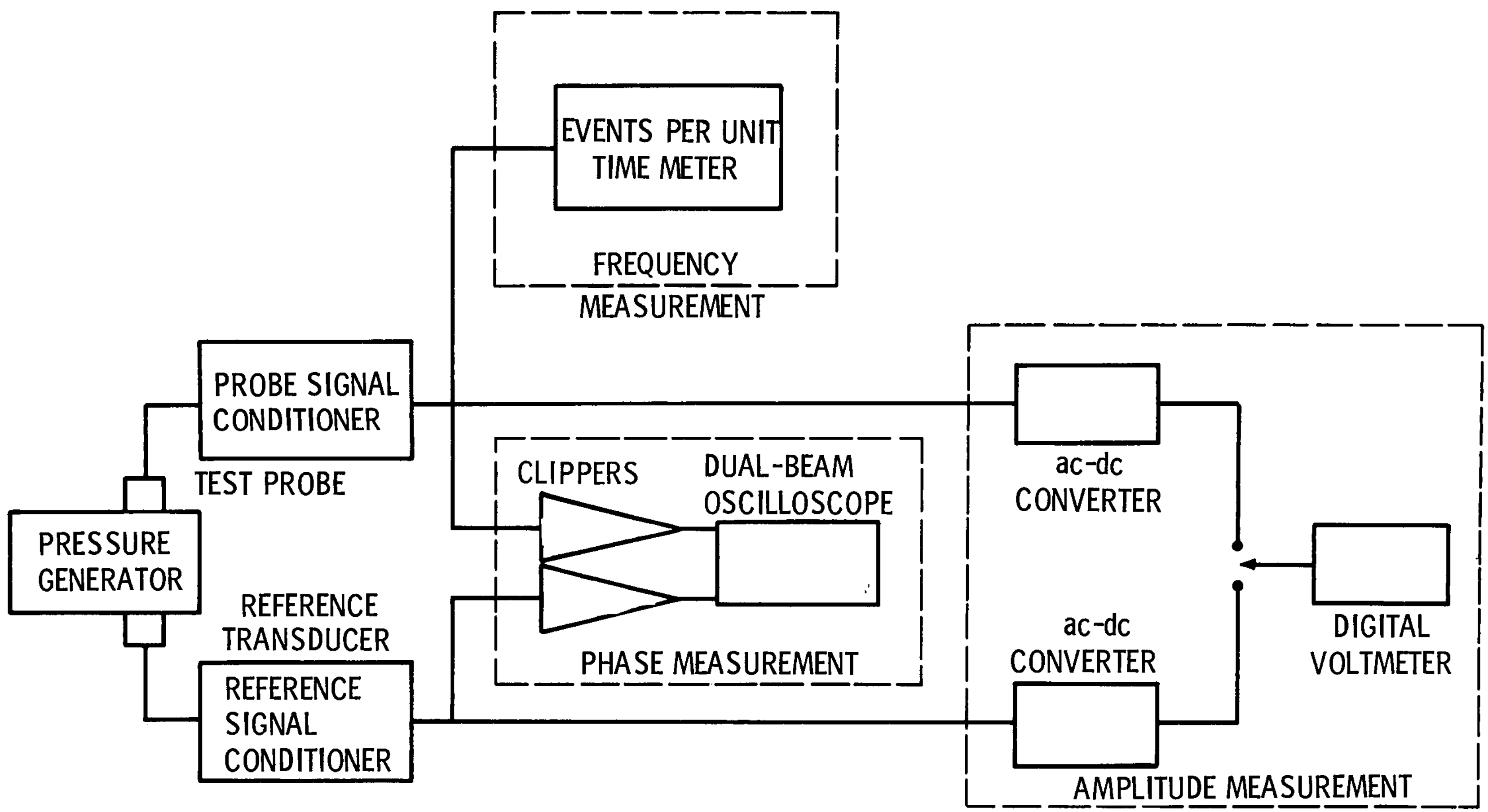


Figure 9. - Instrumentation schematic.

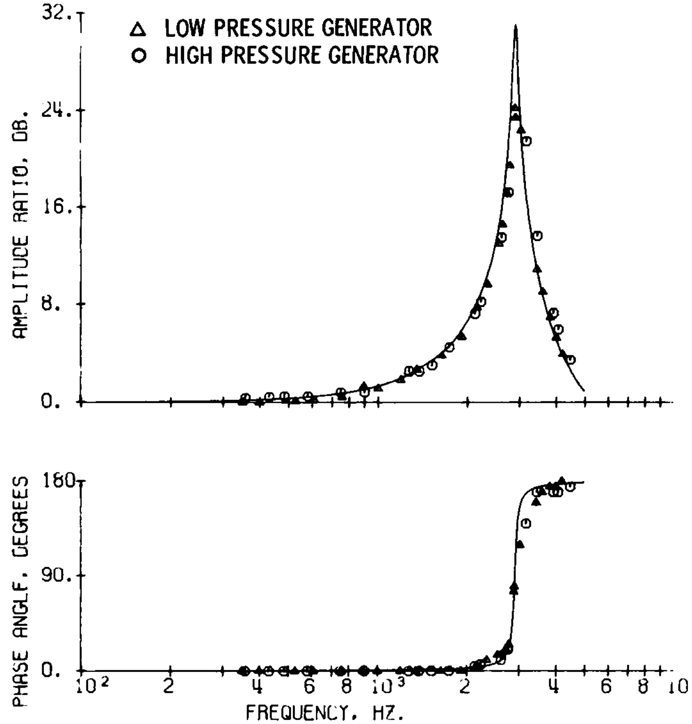


FIGURE 10. FREQUENCY RESPONSE OF A SIMULATED PROBE MEASURED WITH BOTH THE HIGH AND LOW PRESSURE GENERATORS. PROBE LENGTH 1 INCH (2.54 CM). INSIDE DIAMETER 0.128 INCH (0.325 CM). VOLUME RATIO 0.027. STATIC PRESSURE LEVEL 1 ATMOSPHERE. THEORETICAL CURVE CALCULATED FROM EQUATIONS BY IBERAL (REF. 4) INCLUDES END CORRECTION.

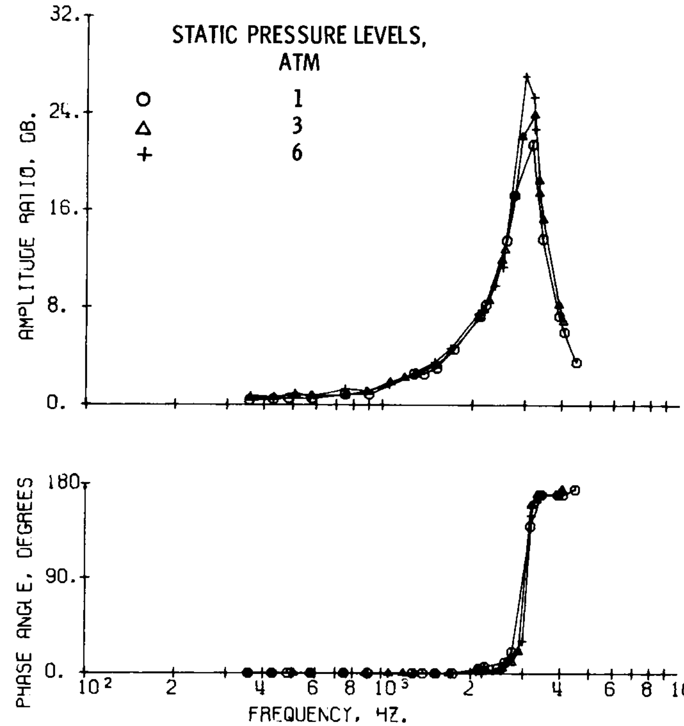


FIGURE 11. FREQUENCY RESPONSE OF A SIMULATED PROBE MEASURED AT THREE DIFFERENT STATIC PRESSURE LEVELS ON THE HIGH PRESSURE GENERATOR. PROBE LENGTH 1 INCH (2.54 CM). INSIDE DIAMETER 0.128 INCH (0.325 CM) VOLUME RATIO 0.027.